ROOT VARIATIONS INDUCED BY CARBON DIOXIDE GAS ADDITIONS TO SOIL[1]

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(WITH NINE FIGURES)

Under discussions of tropisms in plants it has been customary to include statements relative to the tropic influences of gases on plant roots. Primary investigations on this subject were made by Molisch,[2] using seedlings of *Pisum sativum* and *Zea Mays*. Gases were caused to flow past the roots of the plants, and tropic curvatures were reported for all the gases employed. Bennett[3] repeated these experiments and concluded that the results obtained were hydrotropic. Bennett made further studies with *Zea Mays*, *Raphanus sativus*, *Cucurbita Pepo*, *Pisum sativum*, and *Lupinus albus*, both in artificial and in so-called natural media. Studies made with the seedling roots in air gave no indication of aërotropism. Studies made in earth, when the sprouted seedlings were placed between blotting papers in pots of moist earth and then subjected to streams of carbon dioxide gas for periods varying from 24 to 60 hours, gave no definite curvatures.

Cannon and Free,[4] after working with *Prosopis veluntia*, *Opuntia versicolor*, *Fouquieria*, *Coleus Blumei*, *Heliotropium peruvianum*, *Nerium oleander*, and *Salix* (probably *S. nigra*), concluded that "it seems probable that soil aëration must be added as a factor of no less importance than temperature and water," for these plants were found to have different responses to carbon dioxide added to soil. The following quotation is self-explanatory.

[1] Contribution from Research Chemistry and Bacteriology Laboratories of Department of Horticulture, Purdue University Agricultural Experiment Station, Lafayette, Indiana.

[2] Molisch, H., Über die Ablenkung der Wurzeln von ihrer normalen Wachthumsrichtung durch Gase (Aërotropismus). Sitzungsber. Akad. Wiss. Wien.

[3] Bennett, Mary E., Are roots aërotropic? Bot. Gaz. **37**: 241–259. 1904.

[4] Cannon, W. A., and Free, E. E., The ecological significance of soil aëration. Science N.S. **45**: 1917.

The ecological bearing of these facts is manifest. Although deficiency in aëration has frequently been suggested as an agricultural difficulty, or as the reason why certain species do not grow upon soils of heavy texture, it does not appear that this suggestion has had any exact experimental basis, nor does it seem to have been appreciated that different species may have great differences in the oxygen requirement of their roots and widely variant responses to differences in soil aëration, responses which appear to be quite as specific and significant as the responses to temperature and to available water which forms the present basis of ecological classification.

One of the writers[5] reported 2 preliminary experiments with *Zea Mays* and *Lycopersicum esculentum.* Flower pots containing these species were kept surrounded by an atmosphere of carbon dioxide. Practically all the aërial portions of the plants were in normal atmosphere. The plants responded differently to the gas during and subsequent to the 2 weeks' treatment given.

This paper is a report of experiments in which carbon dioxide gas was introduced subterraneously into soil in Wagner pots. Experiments will be reported following up the work of CANNON and FREE, in which the plants will be grown in soil sealed away from the air, so that there is no chance for the oxygen of the air to diffuse down into the soil. Studies on the effects of aëration on bacterial activities have convinced the writers that unless the soil worked with was sterile (which would be unnatural) or contained known organisms of known antagonisms and activities, the responses to changed conditions of aëration might be due to a cessation of certain necessary biological activities, or to the occurrence of certain detrimental biological activities. Adding carbon dioxide gas to the soil was expected to change the biochemical activities of the soil, but by having the atmosphere come in direct contact with the surface, it was believed that necessary biochemical activities could exist, although perhaps closer to the surface than normally. The surface of the soil of all pots was left normal (dust mulch), so that all conditions might more nearly approximate those present when the carbon dioxide content of the soil was increased by natural means. Differences in amount, nature, and type of root growth were thus to be attributed to the carbon

[5] NOYES, H. A., The effect on plant growth of saturating a soil with carbon dioxide. Science N.S. **40**: 1914.

dioxide gas added in equal amounts and in the same manner to all pots receiving gas treatments.

Equal weights of thoroughly mixed soil were put in paraffined Wagner pots of the most approved type (fig. 1). The soil in all pots was compacted by dropping each pot on the cement floor an equal number of times. Distilled water was added through the tubes to bring the moisture content up to one-half saturation, where it was kept by successive additions of water throughout the periods of investigation. The relative position of the pots was changed at regular intervals to correct differences in exposure and temperature in the greenhouse.

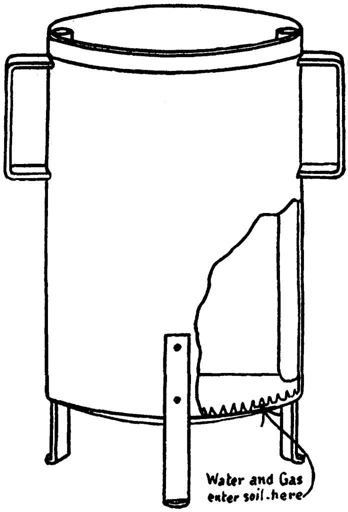

FIG. 1.—Wagner pot showing sub-irrigation tubes in place.

Experiment A

The Christmas pepper (*Capsicum annuum abbreviatum*) was the first plant used. Plants were started in November 1915 in the greenhouse from seed, and transplanted February 1 into the Wagner pots. The soil used was Sioux silt loam. The plants were about 1.5 inches high and carbon dioxide treatments were commenced after the plants became established. Three pots containing 4 plants each received no applications of carbon dioxide, 3 others received carbon dioxide applications 8 hours each day, and yet another set of 3 pots received carbon dioxide applications constantly. The gas was applied at the rate of approximately 650 cc. per hour, and fig. 2 shows the method of getting the gas from the pipe line to the individual pot. The wash bottles served as a means of equalizing the flow of gas into each pot. Fig. 2 shows the Christmas pepper plants after 4 months' treatment. At first the carbon dioxide treatment retarded growth, but by the time the picture was taken there was no great difference in size between the treated and untreated plants. Fig. 3

shows representative roots where no carbon dioxide gas was applied. The roots were uniformly long and fibrous and extended to the bottoms of the culture pots. Representative roots grown where the carbon dioxide treatment was 8 hours per day are shown in fig. 4. These roots did not penetrate to a depth lower than 7 inches. They were clumped and coarser when compared with those to which no carbon dioxide treatment was given. Aërial roots were quite prominent, and the main root was very thickly

FIG. 2.—*Capsicum annuum abbreviatum* 4 months after carbon dioxide gas treatments were started: row of pots fronted by no. 11 received constant carbon dioxide treatment; row fronted by no. 8 received 8 hours' carbon dioxide treatment daily; row fronted by no. 3 received no carbon dioxide treatment.

set with branching roots at a depth of about 3 inches. The roots shown in fig. 5 are representative of those that grew when the carbon dioxide treatment was constant. They compare unfavorably with those obtained under no treatment and under intermittent treatment. Aërial roots are many and prominent. The main roots are dwarfed and coarse and irregular. No roots were found at a depth lower than 5 inches. The carbon dioxide gas added to soil growing the Christmas pepper caused abnormal root developments. The gas had a much greater effect on the root development of the pepper plant than was apparent in the aërial portions.

The soil used for experiments B, C, and D was a fine sand, which has been classified by the Bureau of Soils as Wabash sandy loam. This soil was chosen because of its excellent physical condition and low organic matter content.

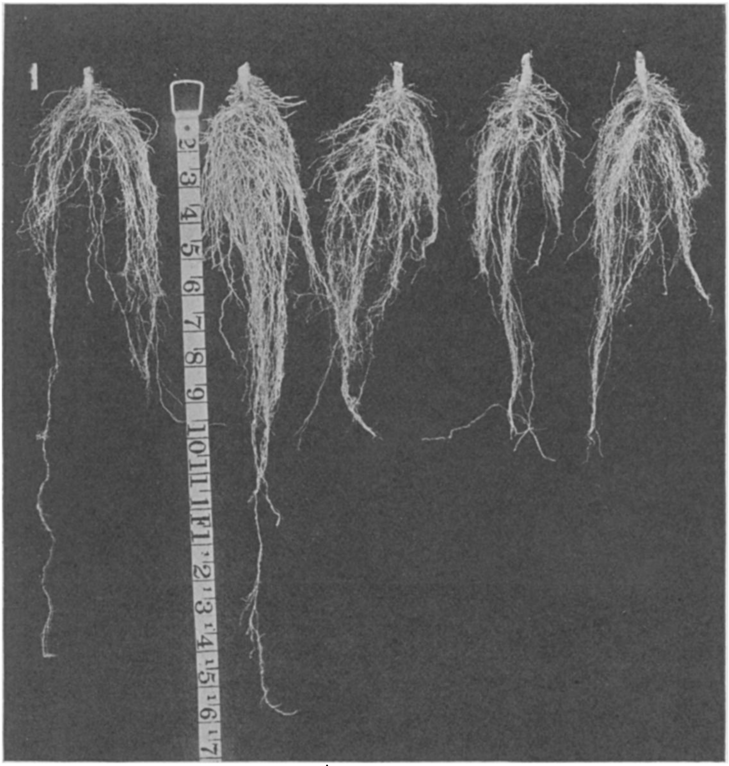

FIG. 3.—Representative roots of Christmas pepper plants which received no carbon dioxide gas treatments.

Experiment B

Head lettuce plants (*Lactuca sativa*) about 2.5 inches in diameter were transplanted into the pots in March 1917. Carbon dioxide treatments were started at once. Fig. 6 shows the best of each of the 3 triplicates. It is noted that carbon dioxide gas appears to have benefited the plants receiving treatment. These plants retained their relative sizes until harvested about 3 weeks later.

Fig. 7 shows the roots from the 2 most representative of each set of 3 plants grown under the different treatments. Carbon dioxide has affected the roots of these plants, although not to the extent that it did those of the Christmas peppers. Root devel-

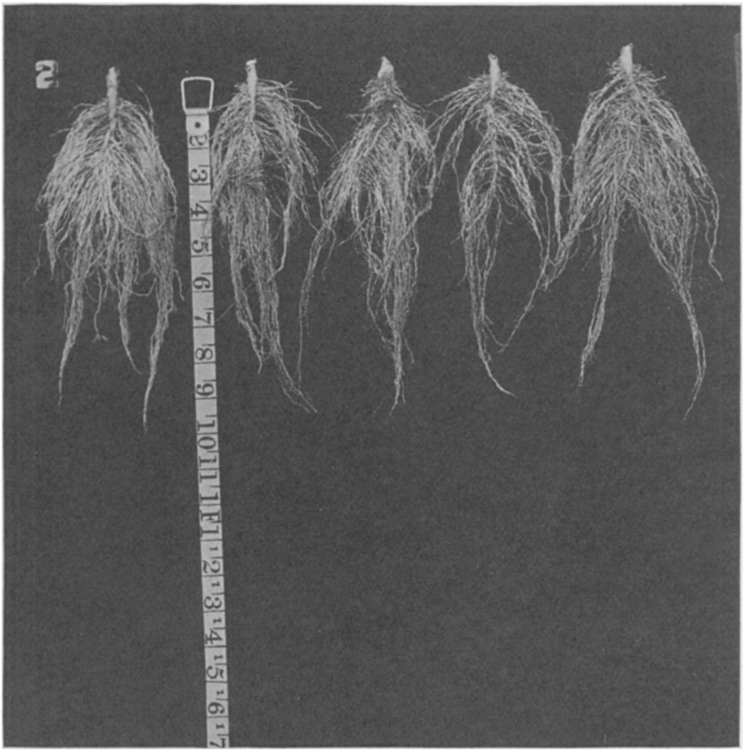

FIG. 4.—Representative roots of Christmas pepper plants which received 8 hours' treatment of carbon dioxide daily.

opment departs from normal with increased carbon dioxide applications.

Experiment C

Radishes (*Raphanus sativus*) of the variety "Rapid Red" were sown in Wagner pots in March 1917. None of the plants were disturbed after the seed was sown. At the time of harvest the series of plants receiving no carbon dioxide gas applications had straight tap roots, while the roots of those receiving the gas showed

a perceptible tendency to horizontal growth. Large numbers of small roots were growing from the base of the bulbs in approximately horizontal directions. No photographs were taken of this experiment.

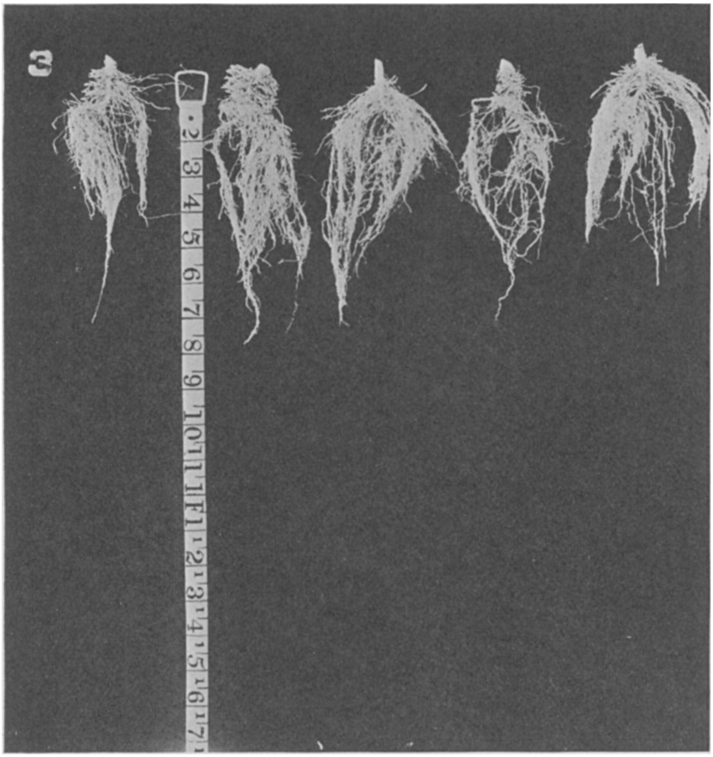

FIG. 5.—Representative roots of Christmas pepper plants which received constant treatment of carbon dioxide.

Experiment D

Burpee's stringless green pod bean (*Phaseolus vulgaris*) was grown from seed without and with the 2 carbon dioxide gas treatments. The plants were harvested just after blossoming ceased. Fig. 8 shows the plants growing in the best of each set of triplicate pots. The difference between the plants growing in the 3 pots is small. Fig. 9 shows the roots of the plants appearing in fig. 8.

Carbon dioxide gas additions to the soil did not prevent the roots from penetrating deeply, for in all pots the roots penetrated to the bottom. It was noted that roots grew to very near the openings

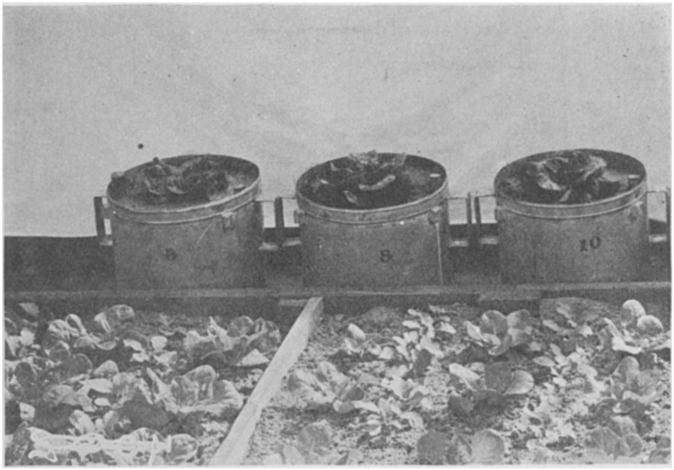

FIG. 6.—Best 3 *Lactuca sativa* of 9 under comparison: pot at left received no carbon dioxide, one in middle 8 hours daily, one at right constant treatment of carbon dioxide.

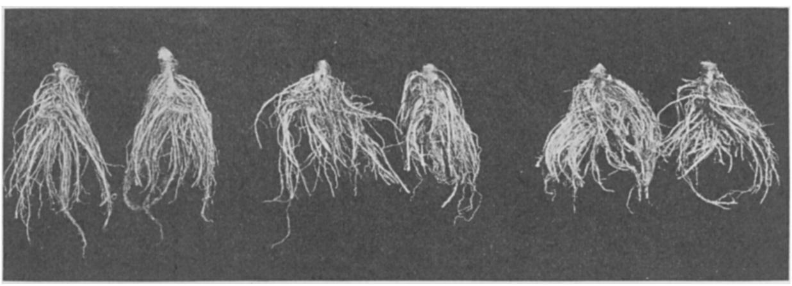

FIG. 7.—Representative roots of *Lactuca sativa:* 2 at left no carbon dioxide treatments, 2 in middle 8 hours' carbon dioxide treatment daily, 2 at right constant treatment with carbon dioxide.

where the carbon dioxide gas entered the pots. The gas had an effect on the development of the roots of the bean plant that was different from that observed with any other plant tested. The

intermittent carbon dioxide treatment was apparently about optimum for the development of the roots of this plant.

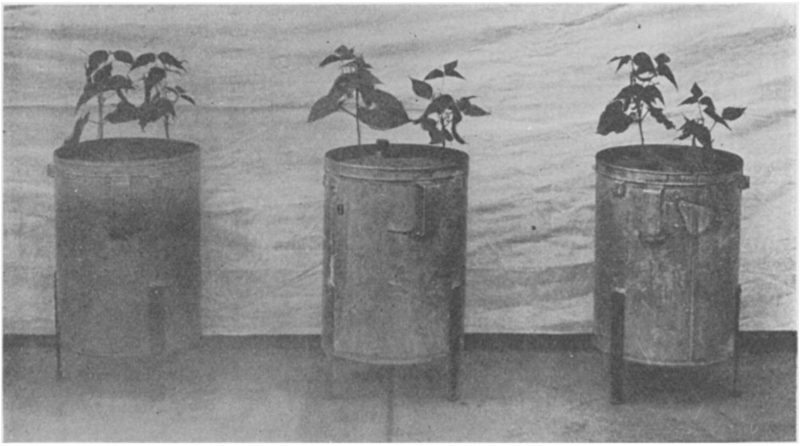

FIG. 8.—*Phaseolus vulgaris* subjected to different carbon dioxide treatments: pot at left received no carbon dioxide treatment, one in middle received 8 hours' treatment daily, one at right constant carbon dioxide treatment.

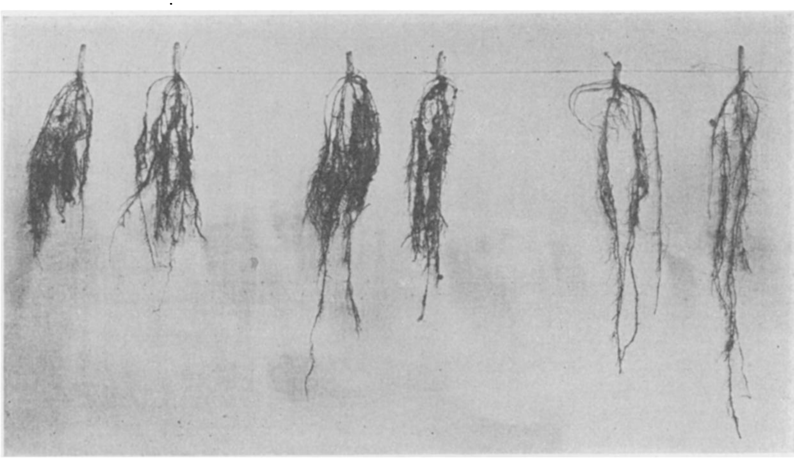

FIG. 9.—Roots of plants shown in fig. 8: 2 at left no carbon dioxide treatments, 2 in middle 8 hours' carbon dioxide treatment daily, and 2 at right constant carbon dioxide treatment.

Summary

1. Plants respond differently to carbon dioxide gas added to the soil in which they are grown.

2. The roots of the Christmas pepper, head lettuce, radish, and string bean were all found to be affected by additions of carbon dioxide gas to the soil.

3. The effects of carbon dioxide on root development were greater than those on the aërial portions of the plants.

4. The intermittent and constant applications of the carbon dioxide gas did not affect the roots of all the plants to the same extent.

5. The effect of the gas was not the same for the different plants used, although a constant treatment of 650 cc. of carbon dioxide gas per hour was apparently preventative of normal root development.

6. Decaying organic matter is held to be beneficial to growing plants. Cases have been cited by others where turning under immense amounts of green material has hurt the land temporarily; therefore the results obtained in these experiments lead to the belief that the carbon dioxide content of garden soils is sometimes detrimental to the root development of some plants growing in the garden.

7. The conclusion of CANNON and FREE that soil aëration must be a factor of no less importance in plant growth than water and temperature is supported.

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